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REPORT NO T3/83

EFFECTIVENESS OF TWO PORTABLE LIQUID-COOLED UNDERGARMENTS IN REDUCING HEAT STRESS

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

APRIL 1983

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The auxiliary cooling provided by each of two portable liquid-cooled undergarments was directly measured on a life-sized sectional manikin. One undergarment (LCU #1) provided cooling over the torso area; the other (LCU #2) provided cooling over the torso and head areas. The liquid contained in both undergarments was cooled by circulating it through an ice-filled compartment (i.e., a heat exchanger). This manikin was dressed in a complete chemical protective (CW) suit in MOPP 4 configuration. Cooling rates (watts) were determined versus time for a completely wet (maximal sweating) skin condition

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during exposure to two hot environments. In a chamber environment of 45°C, the average torso cooling rate over the first hour for LCU #1 is about 94 watts which decreases to about 46 watts over the second hour of cooling; for LCU #2 the average torso and head cooling rates were 81 watts and 67 watts, over the first and second hours, respectively. Only about 20 watts of cooling was still being provided over the third hour of cooling by either portable liquid-cooled undergarment.

OTHER RESEARCH

TECHNICAL REPORT
NO. T3/83

EFFECTIVENESS OF TWO PORTABLE LIQUID-COOLED UNDERGARMENTS IN REDUCING HEAT STRESS

by

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FOREWORD

The cooling rates (watts) provided by various auxiliary cooling undergarments have been determined in biophysical studies using a life-sized sectional manikin. These auxiliary cooling undergarments provided cooling to the surface of the head, torso, head and torso, torso-arms-legs, head-torso-arms-legs or the total surface of the manikin. The coolant used in these undergarments was either a liquid (water), solid (ice), or gas (air). The cooling fluid flowing through the tubing of a liquid-cooled undergarment provides conductive/convective cooling to the surface of the skin directly beneath the tubing. Air-cooled undergarments (e.g., an air-cooled vest) direct the cooling air directly over the surface of the skin where it passes through the clothing to a hot environment. These types of auxiliary cooling undergarments utilize an umbilical cord to connect the undergarment to an externally located heat exchanger. Another type, portable auxiliary cooling undergarments, contains a battery, pump and heat exchanger as part of the cooling unit. These portable cooling undergarments could utilize an AFV's energy when worn by CVC personnel working inside of their vehicle and could be powered by a battery when working outside of the AFV. All biophysical studies evaluating these auxiliary cooling undergarments have been reported in USARIEM Technical Reports except for the study on two portable liquid-cooled undergarments. These are discussed in the present report.

The portable liquid-cooled vest and the portable liquid-cooled vest w/cooling cap were furnished by CPT David M. Terrian, USAFSAM/VBN, Brooks Air Force Base, Texas.

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ABSTRACT

The auxiliary cooling provided by each of two portable liquid-cooled undergarments was directly measured on a life-sized sectional manikin. One undergarment (LCU #1) provided cooling over the torso area; the other (LCU #2) provided cooling over the torso and head areas. The liquid contained in both undergarments was cooled by circulating it through an ice-filled compartment (i.e. a heat exchanger). This manikin was dressed in a complete chemical protective (CW) suit in MOPP 4 configuration. Cooling rates (watts) were determined versus time for a completely wet (maximal sweating) skin condition during exposure to two hot environments. In a chamber environment of 45°C, the average torso cooling rate over the first hour for LCU #1 is about 94 watts which decreases to about 46 watts over the second hour of cooling; for LCU #2 the average torso and head cooling rates were 81 watts and 67 watts, over the first and second hours, respectively. Only about 20 watts of cooling was still being provided over the third hour of cooling by either portable liquid-cooled undergarment.

1. INTRODUCTION

The ballistic protection provided by an AFV for its crew has been continually undergoing modernization. Some of the earlier AFV's utilized extra armor plates welded on the front and/or sand bags strapped to the body of the vehicle. Late model AFV's are employing Chobham armor, side skirts and spacing plates for added ballistic protection. All of these modifications are designed to extend the combat time of the crewmen. The added threat of exposure to a hazardous chemical environment could require that these combat vehicle crewmen operate for extended periods of time in a MOPP 4 configuration. As early as 1963, Goldman (2) had estimated the tolerance time for continuous, moderately-heavy work in environments above 24°C when completely encapsulated in a chemical protective (CW) suit to be only about 30 minutes. A recent field study measured the heat stress on combat vehicle crewmen dressed in MOPP 4 configuration while remaining in a closed-hatch, unventilated AFV and exposed to solar radiation in the hot desert environment of the US Army Yuma Proving Ground, Yuma, Arizona. Toner (4) reported that these crewmen could operate effectively for only 80 and 120 minutes on two different study days. The WBGT inside the AFV was 35°C and the metabolic rate of the crewmen was about 233 watts on the day the study was terminated after 80 minutes. Such findings indicate the need to supply some type of auxiliary cooling for AFV crewmen in CW clothing. A followup study in the NLABS Tropic Chamber (3) using subjects dressed in MOPP 4 configuration and cooled by either an air-cooled or a water-cooled vest concluded that the air-cooled vest could be used with the same efficiency as the water-cooled vest. Both of these auxiliary cooling undergarments required a connection via an umbilical cord to a heat exchanger which maintained the cooling fluid at a constant temperature. The potential for portable liquid-cooled undergarments to

provide combat vehicle crewmen with cooling is excellent over short periods of time (2-4 hours). Two such portable liquid-cooled undergarments are the subject of this report.

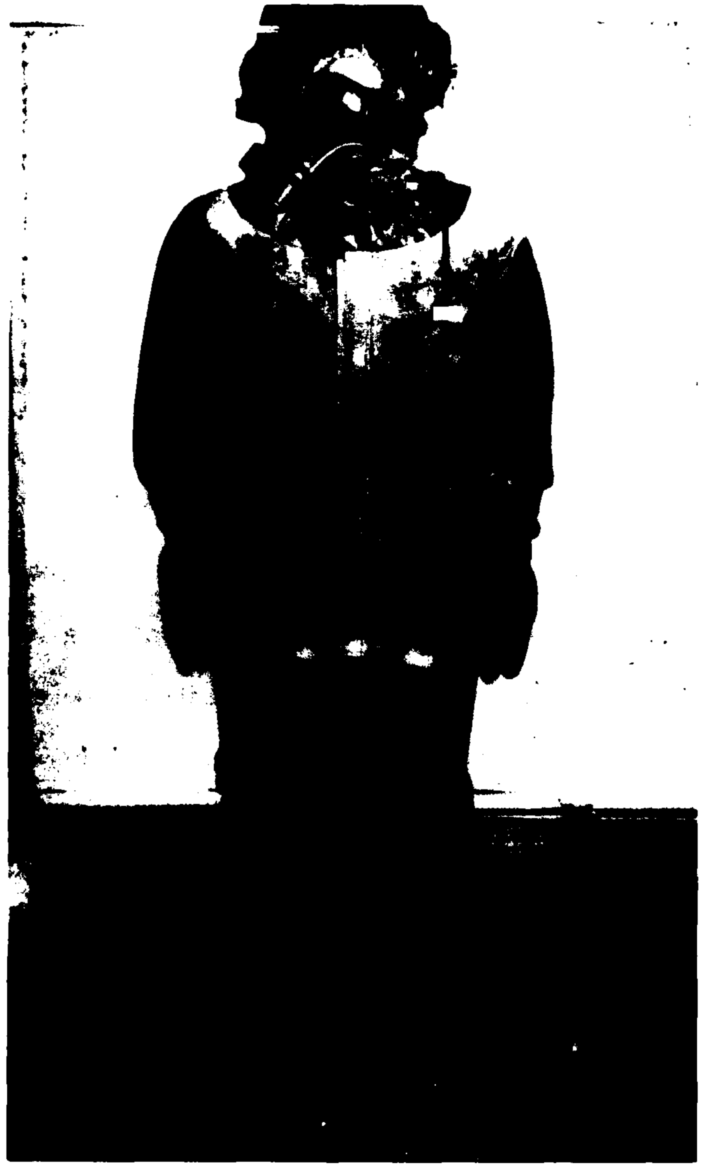

Figure 1. Photograph of the complete chemical protective (CW) suit worn over a fatigue shirt and trousers.

2. EXPERIMENTAL METHOD

The electrically heated sectional manikin consists of six sections: head, torso, arms, hands, legs and feet. This manikin was placed in a standing position in a large temperature and humidity controlled chamber (chamber dimensions: length 5.8 m, width 3.9 m and height 2.7 m). Chamber environmental conditions were either 32°C at 56% relative humidity or 45°C at 46% relative humidity. Duplicate runs were made in each of these two hot chamber environments. Each of the portable liquid-cooled undergarments consists of a vest (plus a cooling cap for LCU #2) containing tubing through which the cooling liquid flows. This fluid is cooled by passing it through a heat exchanger containing one or more frozen ice containers. The battery operated pump, battery, heat exchanger and vest were all dressed on the manikin.

The clothing components were:

Utility Fatigues (Trousers, Men's Cotton)

Utility Fatigues (Coat, Men's Cotton)

Socks, Men's 40% Cotton, 60% Wool

Black Leather Boots

Suit, Chemical Protective-Coat and Trousers (Overgarment)

Glove Set, Chemical Protective

XM-29 Face Piece w/Hood

The chemical protective (CW) suit (Figure 1) and a portable liquid-cooled undergarment were stored in the hot environment prior to dressing on the manikin. This procedure simulates a crewman doning his chemical protective (CW) suit and portable liquid-cooled undergarment which have been heat saturated prior to inserting any frozen containers in the heat exchanger, connecting the battery and switching the pump motor on. A liquid-cooled undergarment was worn next to the manikin skin. The cooling containers used in

a heat exchanger were frozen overnight in a walk-in freezer (air temperature about -20°C). The cooling rates (watts) provided over the torso by the portable liquid-cooled undergarment (LCU) #1 (weight about 5 kg) and over the torso and head by the portable liquid-cooled undergarment (LCU) #2 (weight about 7 kg) were determined from the electrical watts required to maintain the torso (and head) surface at an average temperature of 35°C. Experimentally, these cooling rates are equal to the difference in electrical watts supplied to the torso (or head) when the cooling fluid is providing cooling to the torso (or head) and when the liquid-cooled undergarment is dressed on the manikin and the fluid is not flowing through its tubing. Since the cooling provided by these two liquid-cooled undergarments is time dependent, cooling rates (watts) are plotted against the time that these liquid-cooled undergarments were providing cooling to the torso for the liquid-cooled undergarment (LCU) #1 and the torso and head for the liquid-cooled undergarment (LCU) #2. The cooling rates (watts) are for a completely wet (maximal sweating) skin condition. Cooling time starts at time zero when the frozen containers are inserted into the heat exchanger and the pump motor is switched on.

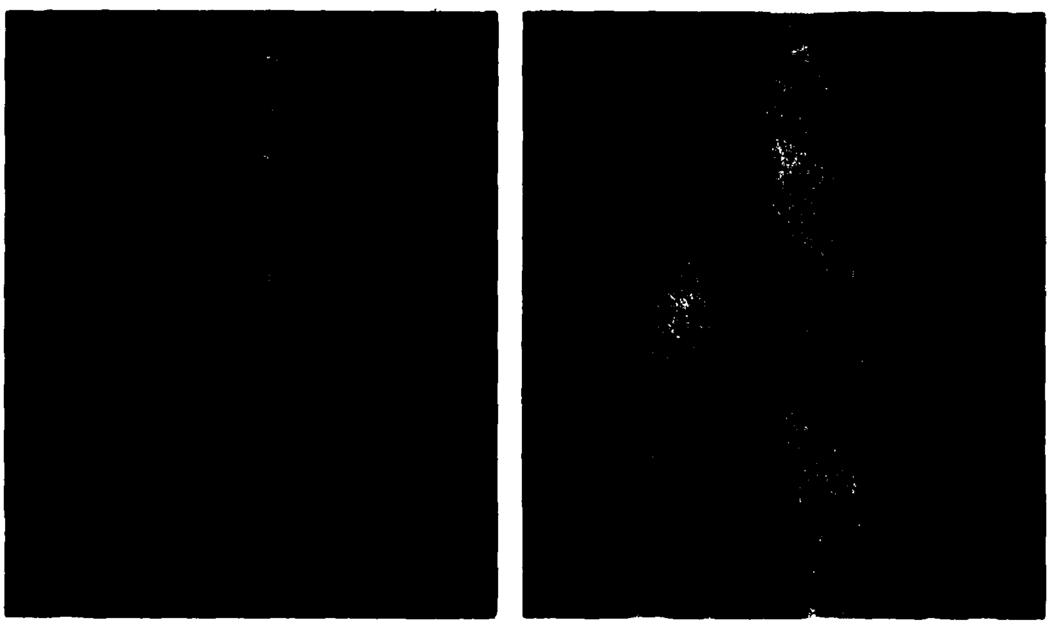

Figure 2. Photographs of the portable liquid-cooled undergarment (LCU) #1: A. Front View, B. Back View.

3. RESULTS

A. Cooling rates (watts) provided over the completely wet (maximal sweating) skin surface area of the torso by the portable liquid-cooled undergarment (LCU) #1.

Photographs of the portable LCU #1 are shown in Figure 2. The component of this LCU containing the tubing is placed on the manikin torso next to the skin. The remaining components (i.e., pump, battery and heat exchanger) are dressed on the manikin beneath the clothing layers covering the torso. The cooling period for this portable liquid-cooled undergarment is limited by the operating time of the battery which supplies power for the pump motor. One run with LCU #1 (for a given experimental condition) was made over a 2-hour period; a second run was extended to a 3-hour torso cooling time by replacing the battery. This battery replacement after two hours of operation apparently did not affect the cooling rate since the curves do not show any abrupt change in slope after 2 hours (Figure 3). These torso cooling watts plotted against the torso cooling time are for exposure to two hot environments. Under the conditions of these experiments there is no leveling off of cooling rate with time; all curves reach a maximum rate of cooling of about 150 watts, then decrease with time. The average torso cooling rate over the first hour is about 94 watts in a chamber environment of 45°C and about 83 watts in a chamber environment of 32°C. These values decrease to about 46 watts and 26 watts, respectively over the second hour of cooling. Some torso cooling is provided for up to three hours of cooling time.

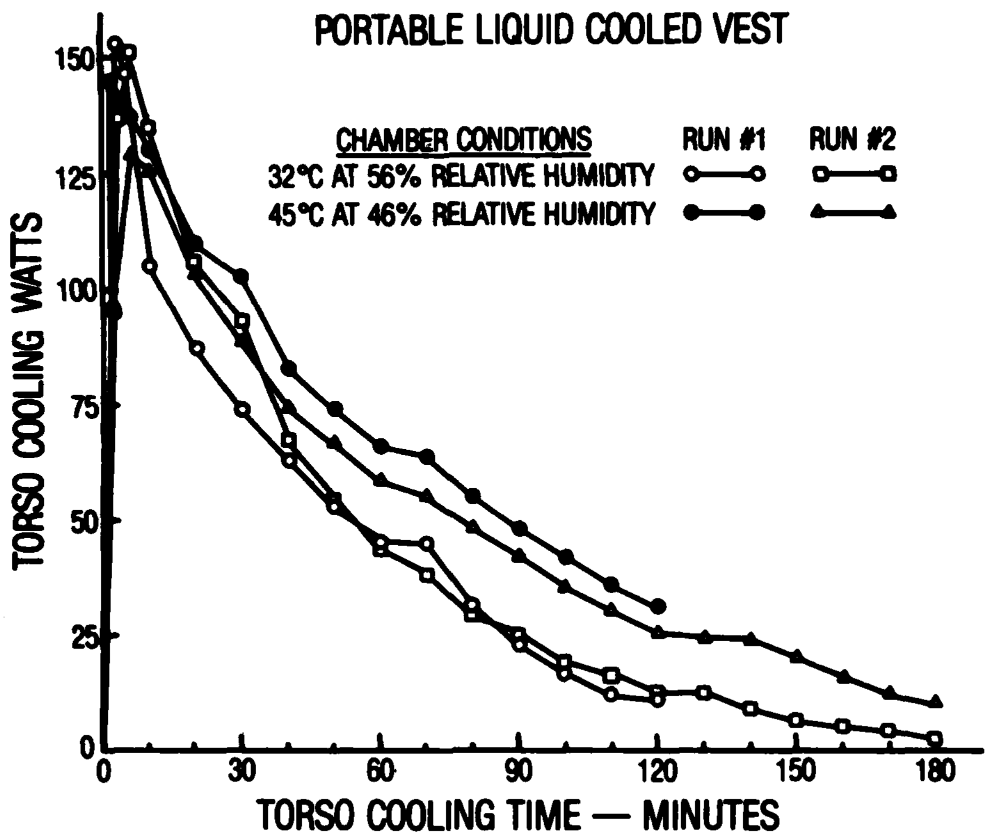

Figure 3. Cooling rates (watts) versus cooling time (minutes) provided over the completely wet (maximal sweating) skin surface area of the torso by the portable liquid-cooled undergarment (LCU) #1.

B. Cooling rates (watts) provided over the completely wet (maximal sweating) skin surface area of the torso and head by the portable liquid-cooled undergarment (LCU) #2.

Photographs of the portable liquid-cooled undergarment (LCU) #2 are shown in Figure 4. The undergarment components (head and torso coverage) containing the tubing through which the liquid flows are dressed on the manikin next to the surface of the skin; the harness containing the pump, battery and heat exchanger is placed over the clothing and carried on the back. Similar to the LCU #1, this portable liquid-cooled undergarment supplies cooling for the 2-hour operating time of the battery. One run for a given experimental condition was made over this 2-hour cooling period; a second run was extended to a 3-hour cooling period by replacing the battery. Both the torso cooling watts and the head cooling watts are plotted against cooling time in Figure 5 for exposures to two hot environments. These curves show that some cooling is being provided to the torso and head for up to three hours of cooling time. A maximum cooling rate of about 126 watts is reached within five minutes after initiating the cooling. The average torso plus head cooling rate over the first hour is about 81 watts in a chamber environment of 45°C and about 67 watts in a chamber environment of 32°C. These values decrease to about 67 watts and 43 watts, respectively over the second hour of cooling. Over a two hour cooling period about 78% of the cooling is provided over the torso and 22% over the head. These percentages are about the same as the percentages of total tubing coverage over the torso and head, respectively.

Figure 4. Photographs of the portable liquid-cooled undergarment (LCU) #2: A. Front View, B. Back View, C. Harness showing two heat exchangers, pump and battery connections.

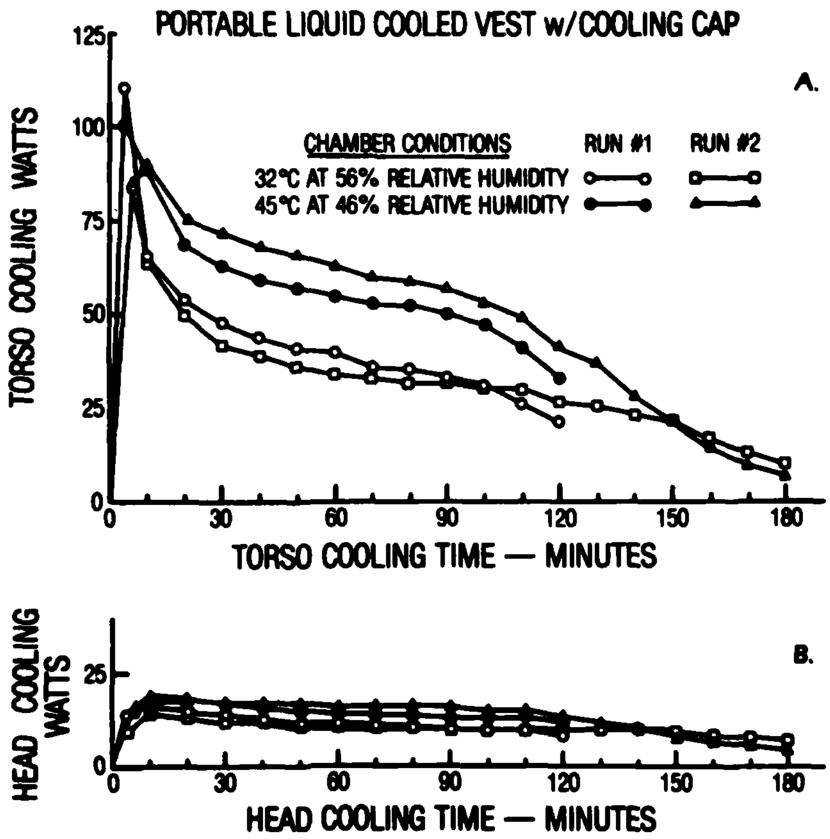

Figure 5. Cooling rates (watts) versus cooling time (minutes) provided over the completely wet (maximal sweating) skin surface areas A. of the torso and B. the head by the portable liquid-cooled undergarment (LCU) #2.

4. DISCUSSION

The concept of a portable auxiliary cooling system analogous to the off-the-shelf portable breathing apparatus used by firemen operating in toxic, gaseous areas of a building has potential for alleviating the heat stress on combat vehicle crewmen operating in a hot, hostile environment which requires that they be completely enclosed in a chemical protective (CW) suit. These auxiliary cooling systems have to be sufficiently rugged to withstand the day-to-day stresses of being stored in an AFV operating over rugged terrain. A supply of charged batteries with sufficient energy to enable a pump to initiate and maintain the flow of the cooling fluid through the tubing of the undergarment is essential. Since the fluid in the tubing of the undergarment will initially be at the temperature of the hot environment, the heat exchanger should have sufficient capacity to provide cooling to a combat vehicle crewman for at least a two hour period, after the initially hot fluid has been cooled down to its operating temperature. To minimize the time lost in inserting a fresh battery and frozen containers, the system should be designed so both would require replacement at about the same time.

The LCU #1 is worn under the clothing. This would require the clothing covering the torso to be removed or modified so that a battery and frozen containers could be inserted or replaced. The LCU #2 has the battery connection and the heat exchanger located over the outer layer of clothing. This permits ready access when the battery and frozen containers have to be inserted or replaced.

5. CONCLUSIONS

These two liquid-cooled undergarments utilize frozen containers to cool a liquid which is then circulated through the tubing of an undergarment by a battery-driven pump. Cooling is provided over the torso by LCU #1 and over the torso and head by LCU #2.

Over a 2-hour cooling period, LCU #1 provided a maximum of 140 watt-hours of cooling over the torso under the test conditions; LCU #2 provided 148 watt-hours of cooling, maximum, over the head and torso. A recent study (1) showed that an ice-packets vest worn in a hot temperature environment of 52°C has the potential of providing about 336 watt-hours of cooling over the torso for a 2 hour cooling period. The cooling potential per unit weight of the complete liquid-cooled undergarment system (i.e., undergarment, battery, pump, frozen containers, fluid, etc.) was 28 watt-hours/kg, maximum, for the LCU #1 and 21 watt-hours/kg for the LCU #2. Comparatively, the cooling potential for the ice-packets vest would be 66 watt-hours/kg. However, this ice-packets vest had a full complement of ice packets; its maximum cooling potential has been obtained. The cooling potential of these two liquid-cooled undergarments could be increased by increasing the efficiency and the capacity of the heat exchanger, the surface area coverage and the flow rate of the cooling fluid.

6. FUTURE STUDY PLANS

As more advanced auxiliary cooling undergarments become available it would be hoped that the Biophysics Branch of the Military Ergonomics Division would have the opportunity to evaluate the heat transfer properties of these items on the sectional manikin for inclusion in their data base for auxiliary cooling undergarments. At present, this data base consists of five USARIEM Technical Reports covering the range of sophisticated liquid or air cooling undergarments that are attached by an umbilical cord to an external refrigeration/control unit which maintains precise control of the temperature and flow rate of the cooling liquid; portable liquid-cooling undergarments which operate independently of any umbilical connection; and a non-sophisticated ice (water) packets vest which can provide several hours of cooling without any additional energy expenditure. Similar to the broad based technical approach used in the design of the new US Army Helmet (PASGT), these studies provide the basic heat transfer data which should be essential inputs into any systematic process of selecting the most appropriate auxiliary cooling undergarment for combat vehicle crewman dressed in MOPP 4 configuration and exposed to a severe heat stress environment.

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